High Data Rate Instrument Study

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High Data Rate Instrument Study - Objectives

- Assess the characteristics of future high data rate earth observing science instruments

- Assess the feasibility of developing data processing systems and communications technologies required to meet those data rates

High Data Rate Instrument Study - Approach

- Identified lead individuals in the key technology areas of science, on-board data management, and telecommunications

- Science team reviewed the current and projected capabilities of high data rate instruments and provided projected data rates from instruments for the years 2000, 2003, and 2006

- Teams assessed the current state of technology and evaluated the technology required to downlink the high data rates projected by the science team. The teams were:

  On-board Data Management
  - on-board storage and processing
  - image compression
  - intelligent data extraction

  Telecommunications
  - x-band
  - Ka-band
  - optical
  - ground data distribution

- GSFC reviewed initial study information and provided corrections, changes, and inputs on their work on RF phased arrays. These inputs were incorporated into the study.

Need for High Data Rate Instruments

- Improved monitoring and management of Earth's resources and environment require the high spatial and spectral resolution obtained by advanced space-borne hyperspectral, SAR and Lidar instruments

- Scientists ranging from geologists, volcanologists, agriculturists, urban planners and environmentalists use hyperspectral data to identify and locate mineral deposits, study atmospheric processes and dynamics, study lava's composition and flow, improve classification of land areas to optimize its use, and improve crop prediction and assess health of crops

High Data Rate Instrument Study - Assumptions

- Technology timeframe for this study is for Technology Readiness dates of 2000, 2003, and 2006. Launch dates are assumed to be at least two years after these dates.
- The orbit of the spacecraft is 700 km in a circular polar orbit and inclined at 98 degrees.
- Data is taken at the full instrument rate over land (approximately 1/3 of the time)
- RF ground stations in Alaska and Norway are asumed to be retrofitted to support high data rates at Ka-Band
- No unplanned new ground station construction is assumed
- RF communications in the V and W bands were not considered
- Lossy compression is unacceptable to the science community

High Data Rate Instruments/Data Rates

Technology Readiness Date	2000	2003	2006
Hyperspectral	1.6 Gbps	3.2 Gbps	40.3 Gbps
SAR	0.18 Gbps	1.3 Gbps	4.8 Gbps
LIDAR	5.0 Mbps	5.0 Mbps	5.0 Mbps

These high data rate instruments will be built, the question is what percentage of the data can be cost-effectively stored and transmitted.

Science Data Storage Requirements/Capability

Technology Readiness Date	2000	2003	2006
Two Orbits (RF Cases)	6.5 Tb	16.2 Tb	162 Tb
Five Orbits (Optical Com Cases)	16.2 Tb	40.5 Tb	405 Tb
Estimated on-board Data Storage Capability	1 Tb	4 Tb	16 Tb
Ratio of Science Data Reduction to Storage Capability			
R F	6.5 (X-band)	4 (Ka-Band)	10 (Ka-Band)
Optical	16	10	25

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Telecom Capability/Storage Capability

Technology Readiness Date	2000	2003	2006
Estimated On-Board Data Storage Capability	1 Tb	4 Tb	16 Tb
RF Cases	0.384 Tb	1.2 Tb	11.5 Tb
Optical Com Case	6.4 Tb	6.4 Tb	6.4 Tb
Ratio of Storage Capability to Telecom Capacity			
RF	2.6 (X-Band)	3.3 (Ka-Band)	1.4 (Ka-Band)
Optical	N/A (not limited)	N/A (not limited)	2.5

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Overall Gap between Instrument Data Generated and Storage/Downlink Capability*

Technology Readiness Date	2000	2003	2006
RF	27	13.2	14
% of Data Generated which can be Downlinked	(3.7%)	(7.8%)	(7.8%)
	X-Band Bandwidth Limited	Storage & Telecom Limited	Storage & Bandwidth Limited
Optical Com	16	10	63
% of Data Generated which can be Downlinked	(6.2%)	(10%)	(1.6%)
	Storage Limited	Storage Limited	Storage & Telecom Limited

* Using current technology approaches projected to 2006 with no new ground stations, no geosychronous communications transfer satellite but with upgrade of Alaska and Norway ground stations from X-Band to Ka-Band capability

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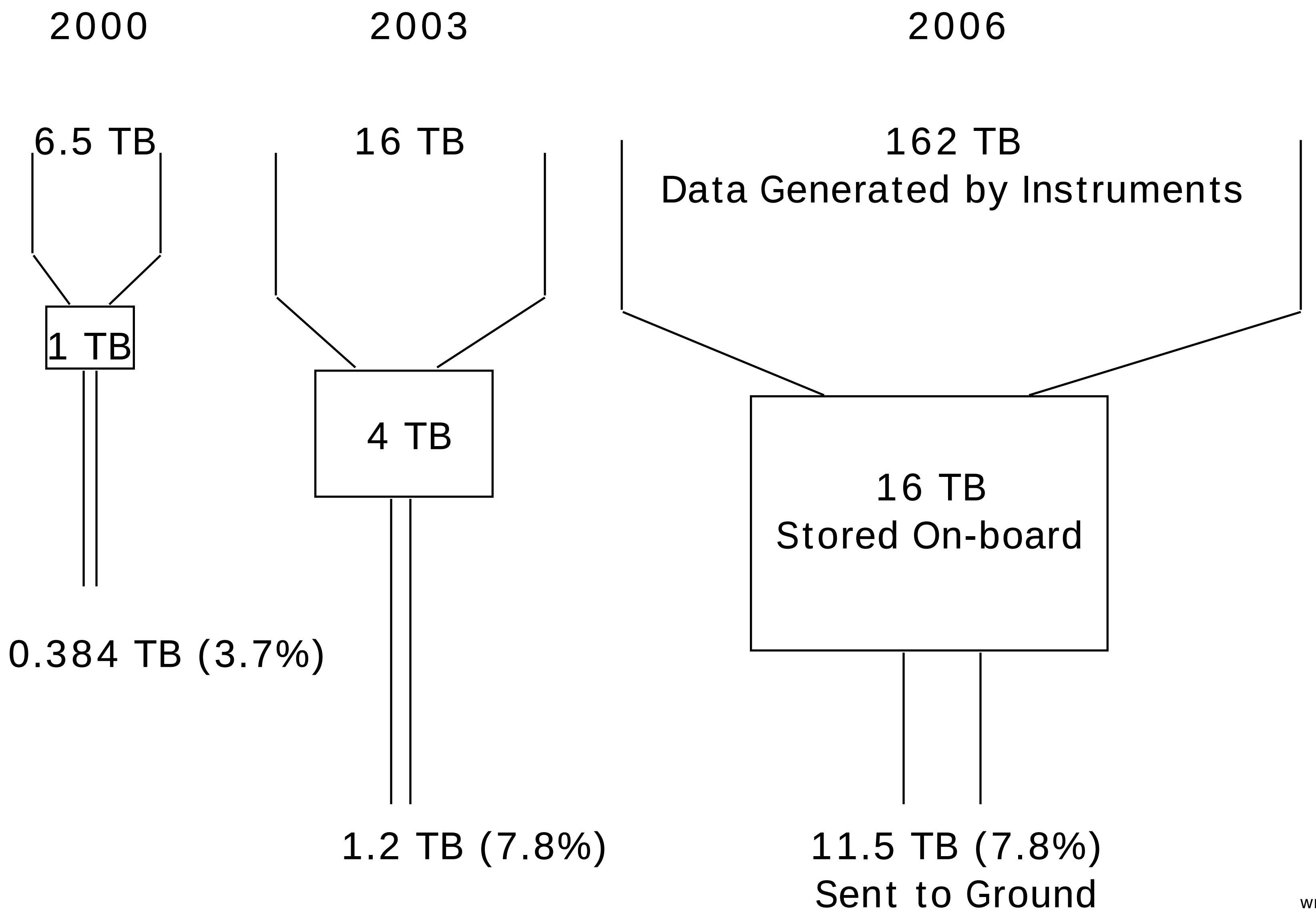
Only 1 - 10% of the Data Will Get to the Ground

(RF Case - Two Orbits of Data)



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Technology Breakthroughs Required

- Only 1 - 10% of instrument data can be downlinked to the ground now and for the forseeable future

- Revolutionary changes is spacecraft design and operations required to increase downlinkable data

  – Intelligent Data Extraction

  – Optical Compression

Intelligent Data Extraction

- Significantly interesting data are extracted and processed onboard the satellite at the instrument level to reduce the requirement for onboard data storage

- Data reduction rates on the orders of 10, 100, and 1000 are possible

- Low-level, mid-level and high-level features can be extracted from the data and reported according to bandwidth availability. For example, the data is collected in different filters or different sources provide multiple information for every pixel, so that each pixel of image data has an n-dimensional vector of values associated with it. The elementary feature-extractor will use mixture-modeling techniques to assign a unique label (can be 2 bits) for each pixel instead of a lengthy multi-dimensional vector (can be 80 bits, for example). This procedure alone can potentially achieve data reduction of one or two orders of magnitude.

- Mid-level information extraction algorithms will cluster low-level features into regions or other descriptive shapes using spatial information further decreasing required data rates by one - two orders of magnitude.

- High-level information extraction algorithms can report statistical information relevant to scientists

- Once the features of scientific interest for available instruments and data scenarios are identified and approved by the scientists, the appropriate algorithms for such feature extraction's will be selected.

Optical Compression

- 100:1 lossless data compression

- Format independent (not restricted to image data)

- Uses optical Fourier transform

  Data is immediately written onto a Spatial Ligtht Modulator, which is then transformed onto a detector - the transform is read out, and may be transformed several more times without data loss.

- Proof of concept demonstrated at OPTS Inc. with SBIR funding which ends in Feb 1999

- $350K is required to validate the technology in a laboratory environment with Earth Science data

Conclusions

- Technology for increasing on-board data storage and downlink communications capabilities are increasing at about the same rate as the increase in data rate of high data rate instruments

- Only 1 to 10% of the data generated by high data rate instruments can be downlinked through the 2006 technology readiness timeframe using current technology approaches

- Current technology development programs in communications, data storage, data processing and data compression must be continued or the gap will increase

- Intelligent data extraction can fill the gap in the technology readiness cases of 2000 and 2003, but the power and mass requirements for a data processing system for the 2006 case becomes prohibitive

- Lossy data compression could fill the gap, but is generally considered unacceptable to the science community

Recommendations

- Continue existing technology development programs for on-board data storage and downlink communications

- Develop Intelligent Data Extraction Technology

  - Technology under development in Cross Enterprise Technology Development Program

  - A specific program for Hyperspectral instruments is required
    - estimate 350K per year for three years; initial funding will show feasibility on existing hyperspectral data sets

- Develop Optical Compression - $350K for Technology Validation

- Determine cost and schedule to upgrade ground station receivers and antenna in Alaska and Norway to support high data rates at Ka-band

- Study the feasibility of creating a geosynchronous optical data transfer capability which solves the downlink bottleneck

High Data Rate Instrument Study - Report Contents

- Executive Summary
- Introduction
- Instrument data rates needed to support the future high spectral and spatial resolution hyperspectral imaging instruments, the lidar and the synthetic aperture radar.
- Onboard processing of data and intelligent data extraction at the instrument level
- DRAM and disk-drive onboard data storage options that would support the instrument data rates and onboard processing
- Data compression of imaging data that will facilitate the recovery of higher data volumes using lower telecommunications data rates.
- General telecommunications architecture (X-band, Ka-band, and optical telecommunications spacecraft transceivers)
- Configuration of the optical ground station for the high-data-rate reception
- Data-distribution approaches that are expected to be available to stations located within the continental United States (CONUS)
- LEO-to-GEO and GEO-to-ground-relay optical link in section
- High-speed data storage and distribution from the ground stations
- Mass and power consumption for the spacecraft telecommunications system along with the estimated costs for the spacecraft RF and optical communications terminals; cost estimates for data delivery, i.e., for connecting the ground station to the WAN.
- Conclusions and recommendations